Heavy construction equipment noise study using dosimetry and time-motion studies[1)]

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Noise induced hearing loss continues to afflict workers in many occupational settings despite longstanding recognition of the problems and well-known methods of prevention and regulations. The focus of this research was to determine the noise exposures of heavy construction equipment operators while documenting the workers' tasks, (i.e. hauling, moving, and/or pushing construction material). Time-motion studies were performed at the construction sites and were used to correlate the noise dosage with the work performed by the equipment operators. The cumulative dose for each operator was then plotted with references to work tasks. This was done to identify the tasks that caused the greatest noise exposure. Three construction sites were studied for this research. The types of construction equipment studied included asphalt pavers, backhoes, bulldozers, compaction equipment, excavators, haul trucks, telehandlers, and wheeled loaders. The results indicate that the majority of operators were over-exposed to hazardous noise.

1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) estimates that in 1995 about 754,000 U.S. construction workers are exposed to potentially hazardous noise levels above 85 dB(A)[1]. Sound levels associated with heavy construction equipment range from 80 to 120 dB(A) and power tools commonly used in construction produce sound levels up to 115 dB(A)[2].

The bulldozer operators consistently had the higher continuous noise exposures ranging from a NIOSH REL (Recommended Exposure Limit)[3] $dose_8$ of 844% to 25,836%. This dose equates to an OSHA PEL (Permissible Exposure Limit) $dose_8$ of 139% to 1,397%. Technologically achievable engineering noise controls can reduce the total sound level reaching the bulldozer operator by as much as 3 dB(A). This could potentially reduce the REL $Dose_8$ of the operator by 13,036%. In the construction industry, heavy construction equipment is a major contributor to high noise levels at most job sites. In a paper by Alice H. Suter[4] over 100 studies and reports pertaining to construction noise are cited. The use of time-motion studies of work tasks along with the operator's daily dose are not being used in most of these references with only one study identified as directly using one-minute sound levels by work-task. The current study was performed to identify the overall A-weighted sound levels of heavy construction equipment and the resultant occupational noise exposure of the operators during normal operation in correlation to work-tasks. Dosimeters were used to measure the noise levels and calculate the operator's daily noise dose over an 8-hour shift ($dose_8$) using NIOSH criteria, Wide Range (for L_{eq}), and OSHA criteria. The NIOSH REL (Recommended Exposure Limit) is 85 decibels, A-weighted, as an 8-hr time-weighted average (85 dB(A) as an 8-hr TWA) with a 3-dB exchange rate. The NIOSH recommendation further states that: "Exposures at or above this level are hazardous."[3] Therefore the data will be presented using the NIOSH REL criteria and the corresponding work-task. Suter[4] also recommends that a noise control database be developed, which was started with this study. The correlation of dosimeter and time-motion studies can be used to identify and prioritize noise control efforts, including maintaining designed noise controls, retrofitting engineering noise

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1) The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute of Occupational Safety and Health (NIOSH). Also, reference to specific brand names does not imply endorsement by the NIOSH.

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Table 1—Internal dosimeter settings[5].

Designation	Parameters	Settings	Designation
Dose Measurement 1	Weighting	A	
	Threshold Level	80 dB	NIOSH Recommended Exposure Level (REL)
	Exchange Rate	3 dB	
	Criterion Level	85 dB	
	Response	Slow	
	Upper Limit	140 dB	
Dose Measurement 2	Weighting	A	
	Threshold Level	40 dB	Wide Range (L_{eq})
	Exchange Rate	3 dB	
	Criterion Level	85 dB	
	Response	Slow	
	Upper Limit	140 dB	
Dose Measurement 3	Weighting	A	
	Threshold Level	90 dB	OSHA Permissible Exposure Level (PEL)
	Exchange Rate	5 dB	
	Criterion Level	90 dB	
	Response	Slow	
	Upper Limit	140 dB	
Dose Measurement 4	Weighting	A	
	Threshold Level	80 dB	OSHA Action Level
	Exchange Rate	5 dB	
	Criterion Level	85 dB	
	Response	Slow	
	Upper Limit	140 dB	

controls, administrative noise controls, and the use of personal protection equipment. Some recommendations on noise control treatments, estimated costs, and quieted noise levels, will also be discussed in this paper

1.1 General Instrument and Measurement Information

The noise measurements were obtained using Larson-Davis Spark™ 705+ dosimeters because they are capable of measuring and recording dose with four separate noise criteria and sampling at a 1-second interval over 13 hours[5]. The dosimeters were programmed as shown in Table 1. The noise measurements using the OSHA settings (shown in Table 1) were used primarily for informational purposes (i.e., a reference for the operators who must comply with the OSHA regulations, refer to Table 2). The areas where noise controls were most needed were determined by examining the percentage of workers exceeding 100% dose based on the NIOSH REL. A Personal Digital Assistant (PDA) with subject observation software or a watch combined with handwritten notes were utilized to conduct task observations on the equipment operators. These observations were used to define their activities, behaviors, and machine functions occurring during their work shift.

1.2 Data Collection

The machine type, manufacturer, model, and serial number and the engine manufacturer, model number, power rating, and rated speed were documented via handwritten notes on data sheets. In addition, the condition of the machine, existence of engineering noise controls, and modifications to the machine were also noted. When practical, digital pictures were taken of each side of the machine, the engine compartment, and the operator station. Further, close-up pictures were taken of installed engineering noise controls and observed damage such as broken windows or missing door seals were noted. The dosimeters were calibrated prior to and after each measurement. The dosimeter microphone was clipped to the midpoint of the worker's shoulder with the diaphragm pointing up[6] and the time that the dosimeter microphone was first placed on the worker and the time of removal were documented.

1.3 Data Analysis Plan

The dosimetry results were examined with the aid of task observations to determine the tasks, behaviors, and machine operations that resulted in the highest noise exposures. Documenting worker activities enabled the researchers to correlate sound levels at the operator ear during work-tasks under field conditions. Sufficient data were collected to document and determine where noise control development was necessary by identifying the machines whose operators were over-exposed to noise in excess of 85 dB A-weighted sound levels at the operator's position. The dosimetry results were downloaded into a searchable database. The task observations were imported into an Excel dosimetry macro to facilitate determination of the significant contributors to the workers noise dose.

2 RESULTS

Table 2 shows the range of time-weighted average noise doses and the length of time the operator was monitored. The range in the operator's dose for a specific machine can be attributed to factors including but not limited to: hours worked, the monitoring of different operators, the operators' degree of expertise, the condition of the terrain, the presence of or the proximity of noisy equipment, and quantity of

Table 2—Citation values of tonal targets in the experiments with three speakers.

Machine (Number Sampled)		NIOSH REL $Dose_8$ (%) Range	OSHA PEL $Dose_8$ (%) Range	Noise Exposure Level dB(A)	Monitor Time (minutes)
Dozers	Bulldozer (10)	844–25,836	139–1,397	92–109	362–630
	Older and No Cabs	6,557–25,836	523–1,397	102–109	362–630
	Newer with Cabs	1,245 – 2,458	191–356	95–99	420–630
	Newest and No Cab	844	139	92	575
Saws	Hand Saw (2)	4,094–9,194	173–301	94 – 98	74–164
	Road Saw (2)	1,242–2,090	108–265	90.5–97	155–415
Trucks	Haul Truck (6)	28–492	24–165	80–92	479–630
	Trucks with AC	28 – 55	24–35	80–82	479–630
	Trucks without AC	174–492	104–165	90–92	479–630
Others	Road Grader (1)	3,023	252	97	630
	Tele-Handler (1)	472	64	87	463
	Asphalt Paver (3)	150–460	17–76	78–88	328–550
	Front End Loader (4)	18–200	2–17	76–78	500–539
	Excavator (4)	7–155	0–16	75–78	480–630
	Plate Tamper (3)	62–146	7–23	76–80	508–510
	Multi-Machine (17)	31–3,084	2–392	76–100	70–630

construction work done. For bulldozers, the age, size, and work-cycle were all factors affecting the operator's dose. The bulldozer operators were consistently overexposed to noise based on both the NIOSH REL and OSHA PEL criteria. Again, some of the wide ranges of TWA $doses_8$ can be attributed to hours worked, a ten-hour shift will have a much higher $dose_8$ than an eight-hour shift under the same noise (>85 dB(A)) conditions. While the data from Table 2 can be used as a reference, every construction site should do their own noise survey to determine their workers' noise exposure to base their Hearing Loss Prevention Program[3] on. If an individual daily noise dose is unusually high, that operator or job position should be observed and more noise control methods applied[3].

Figures 1–7 show selected samples of the cumulative dose for operators of various types of equipment. Note that the ordinate (y-axis) is different for each figure due to the large range of values. The higher noise

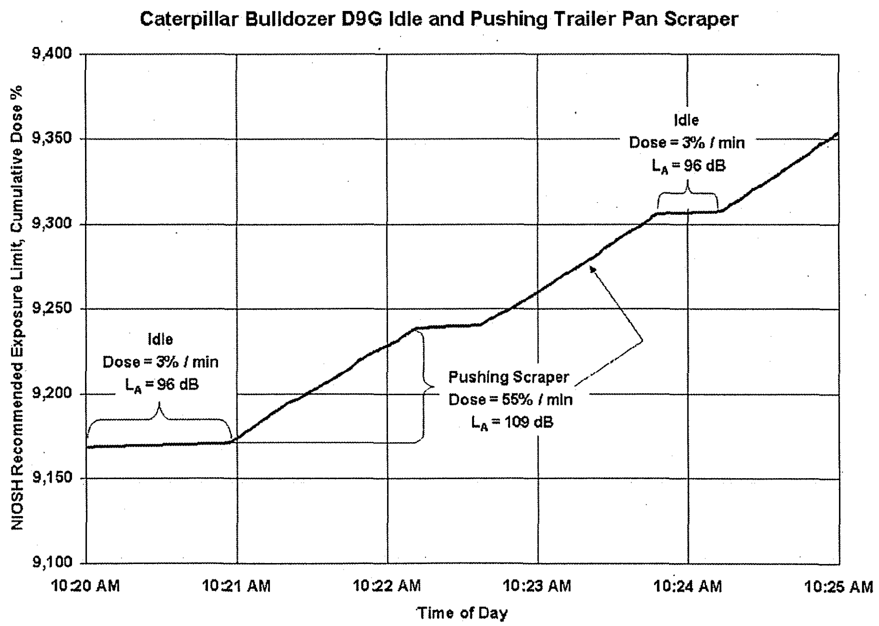

Fig. 1—5-minute work-cycle of a Caterpillar D9G Bulldozer Operator.

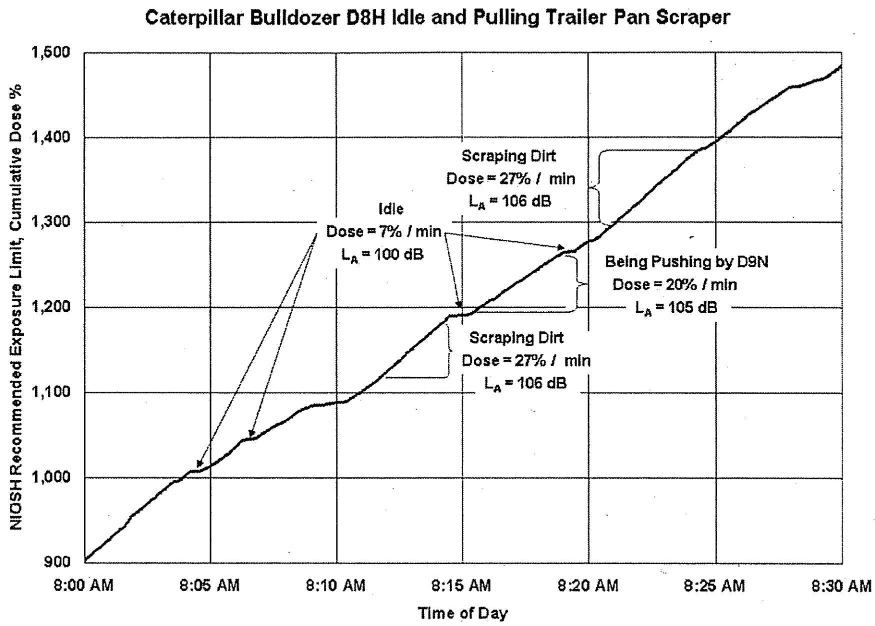

Fig. 2—30-minute work-cycle of a Caterpillar D8H Bulldozer Operator.

doses came primarily from the largest bulldozers (shown in Figs. 1 and 2). These included the Caterpillar Bulldozer D8Hs and D9G which only had Roll-Over and Falling-Object Protection Systems (ROPS/FOPS) and stack exhausts without mufflers. The exhaust stacks on these machines ended at approximately the height of the ROPS/FOPS. This appears to be a significant source of the operators' noise exposure. The A-weighted equivalent continuous sound levels (L_{eq}) measured with the dosimeters ranged from 104 to 108 dB for the bulldozers. The older Caterpillar D8H and D9G Bulldozers were built from the late 1960's to early 1970's, but appeared to be in good condition despite their age. The newer Caterpillar D8N Bulldozers had cabs with ROPS protection (cumulative dose is shown in Fig. 3). It was observed that the cabs had little or no sound absorbing material inside. The seals around the cab doors were in poor condition. The operators were observed to operate the Caterpillar D8Ns Bulldozers with a combination of doors and/or windows open, thereby greatly reducing the ability of the cab to protect the operators from hazardous noise.

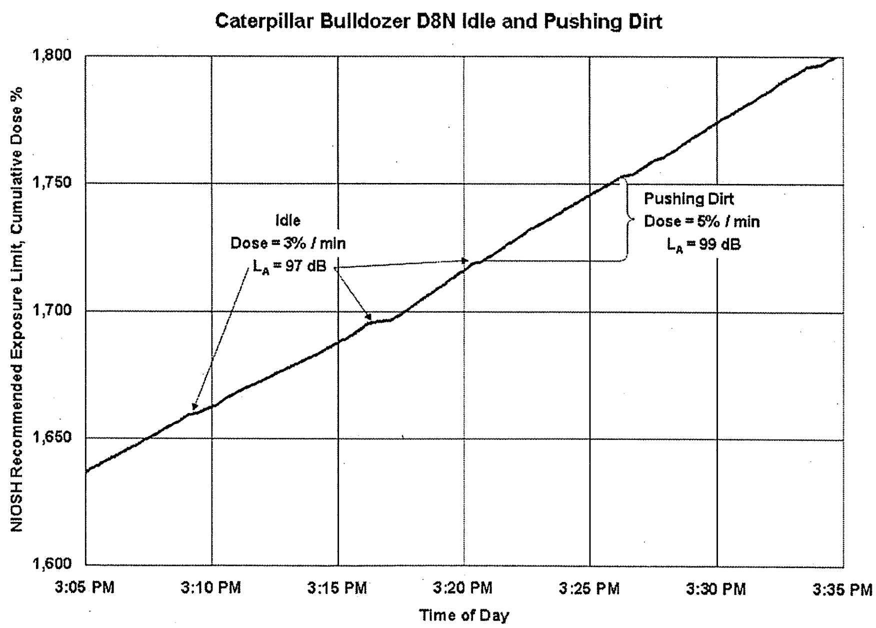

Fig. 3—30-minute work-cycle of a Caterpillar D8N Bulldozer Operator.

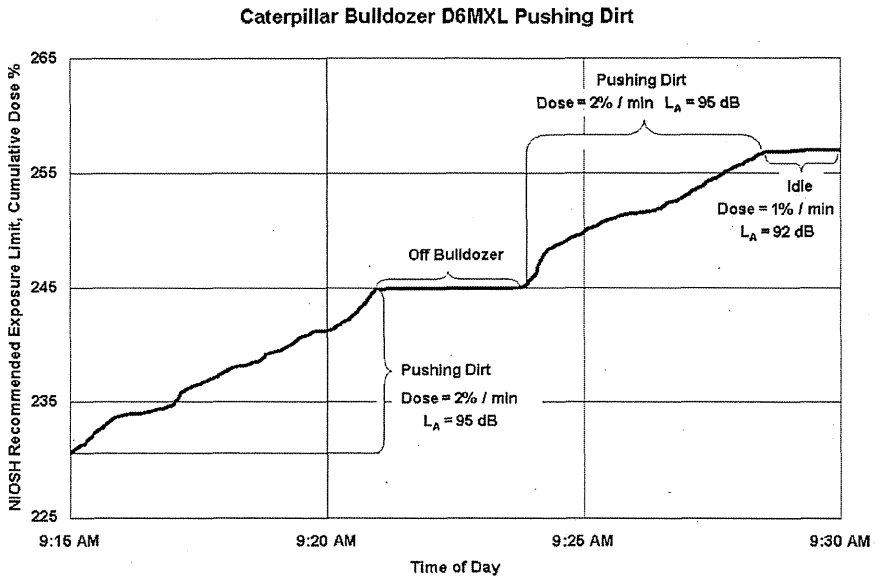

Fig. 4—15-minute work-cycle of a Caterpillar D6MXL Bulldozer Operator.

The air conditioning units on the Caterpillar D8Ns Bulldozers were not functional. If the units worked, perhaps the workers would use the air conditioning and keep the cab doors and windows closed. The newest bulldozer studied was a Caterpillar D6MXL having noise controls consisting of acoustic foam on the ceiling of the ROPS/FOPS, an exhaust muffler, and an enclosed engine compartment. Even with no cab, the Caterpillar D6MXL Bulldozer had the lowest operator's dose of all the bulldozers (Fig. 4).

The road grader had a cab, but no insulation on the walls, floor, or ceiling and the doors were left open during operation. The highest sustained dose was recorded when the grading was done uphill (Fig. 5). In this case the engine noise appears to be the significant source of the operator's noise exposure, since the exhaust muffler was in good condition and the exhaust is directed away from the cab.

The gas powered hand saws used 6″ abrasive circular-disk blades to cut relief-joints in a concrete road and re-bar from broken concrete slabs. The saw operator was exposed to noise from the cutting operation and the exhaust of the engine. The road saws had 26″ toothed circular blades that were used to cut a concrete road into approximately 6′ by 6′ slabs so they could be easily removed. The road saw operators were

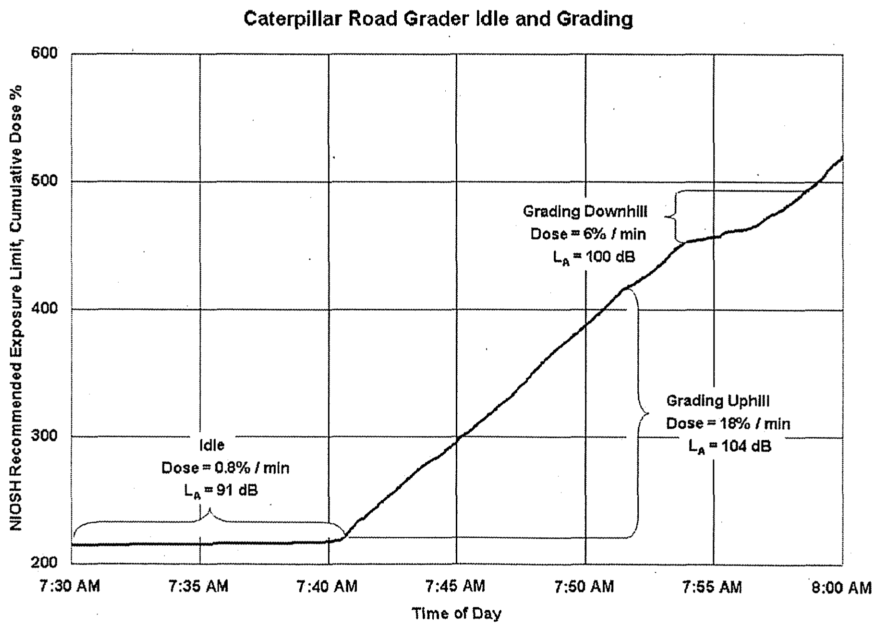

Fig. 5—30-minute work-cycle of a Caterpillar Road Grader Operator.

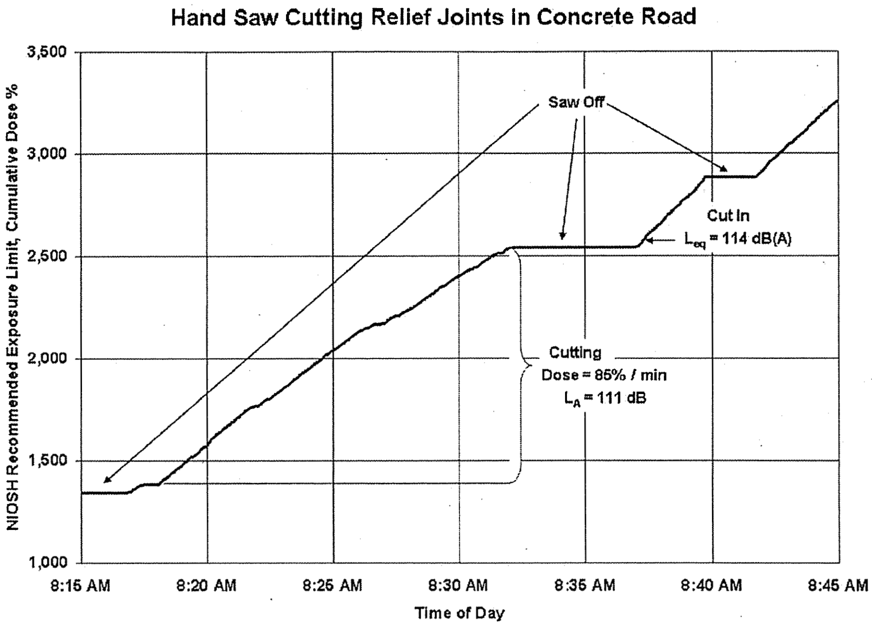

Fig. 6—30-minute work-cycle of a Hand Saw Operator.

not as close to the cutting operation as were the hand saw operators. Because the road saws were automated and had good mufflers, the operators were exposed to less noise than the hand saw operators (Fig. 7).

All of the haul trucks were similar in size, but the operators of the newer trucks with air-conditioning had lower noise exposures than the operators of the older non-air-conditioned trucks, even though the new trucks were operated with the driver-side window open. Note that in Table 2 the operators of the non-air-conditioned trucks were over-exposed and exceed the NIOSH REL as well as the OSHA PEL.

Several operators used multiple machines during the observed time. Those operators were grouped in the multi-machine category, which consisted of several different machines including backhoes, soil compactors, front-end loaders, and/or excavators, that were operated as the need arose. The noise dose for the operators of these machines was included in Table 2 to show the high variability of noise doses at construction sites.

Table 3 lists the observed work-task that subjected the operator to the greatest noise exposure during a work-shift. Using one bulldozer operator's cumulative

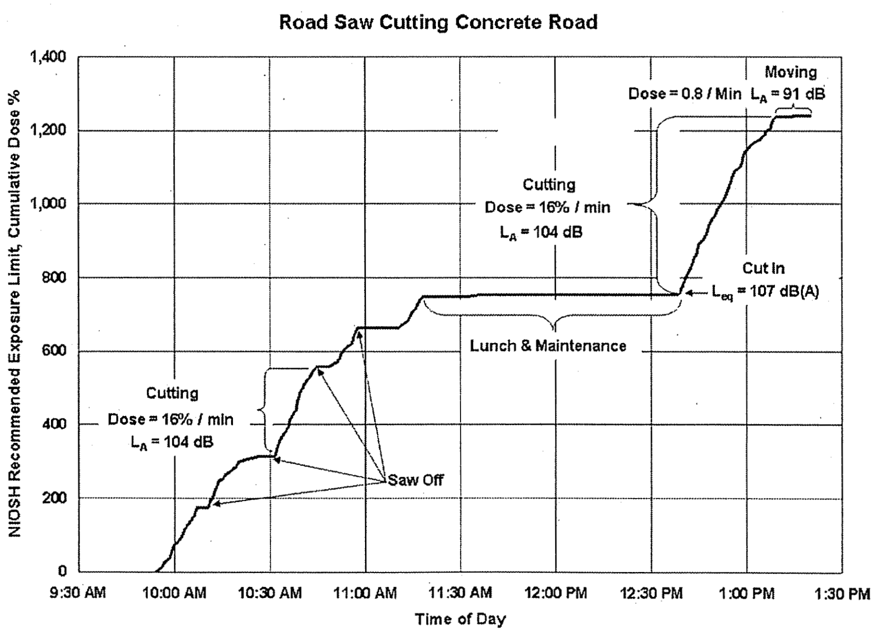

Fig. 7—Cumulative NIOSH Noise Dose of a Road Saw Operator, running from 9:50 AM until 1:20 PM.

Table 3—Tasks that cause the greatest noise exposure.

Machine	Observed Task	Graph Example
Bulldozer D9G	Pushing Trailer Pan Scraper	1
Bulldozer D8H	Scraping top-soil into Pan	2
Bulldozer D8N	Pushing soil uphill	3
Bulldozer D6MXL	Pushing soil uphill	4
Road Grader	Grading haulage road uphill	5
Hand Saw	Initial cut into concrete	6
Road Saw	Initial cut into concrete	7

NIOSH noise dose and the bulldozer's approximately 2-minute idle/push work-cycle as an example from Fig. 1, the following details the operator's noise exposure. For this example, a 5-minute period (10:20 – 10:25) is used at a time when all of the bulldozer operators were working together in a small job site and the operator had the highest and most sustained noise levels compared with the other operators. The Caterpillar D8Hs Bulldozers were used to pull a Trailer-Pan Scraper (Scraper) and the Caterpillar D9G Bulldozer operator (shown in Figs. 1 and 2) helps the Scraper cut into the soil by pushing the Scraper. This work-cycle was done continuously, all day, in a confined area with a short uphill trip to the dumpsite where a Caterpillar D8N Bulldozer was working—all contributing to the high noise exposure. Even at idle the Caterpillar D9G Bulldozer operator was exposed to an A-weighted sound level (L_A) of 96 dB shown in the 1-minute from 10:20 to 10:21. Staying at idle for a full shift would result in a REL $Dose_8$ of 1270%. The highest noise exposure of 109 dB(A) was recorded when the bulldozer pushed the Scraper, resulting in the operator's daily noise $dose_8$ of 25,835% (NIOSH REL). At the higher noise level both earplugs and earmuffs should be worn, but NIOSH cautions that even double protection is inadequate when TWA exposures exceed 105 dB(A).[3] The newer Caterpillar D8N Bulldozer (Fig. 3) pushed and compacted fill unloaded from the Scraper to level a ramp and would pause occasionally during the unloading. This bulldozer operator was exposed to an A-weighted sound level (L_A) of 99 dB(A) during the push-dirt work-cycle. Even at low idle the operator was exposed to an A-weighted sound level (L_A) of 97 dB(A). The newest bulldozer studied was a Caterpillar D6MXL, even with no cab, this bulldozer had the lowest operator's daily dose at 844% (refer to Table 2). In Fig. 4 at low idle, the operator was exposed to an A-weighted sound level (L_A) of 92 dB(A). More significantly when pushing dirt, the operator was only exposed to an A-weighted sound level (L_A) of 95 dB(A). This is up to 14 dB less than the operator of other bulldozers. This can be attributed to the engineering noise controls consisting of an enclosed engine compartment, acoustic foam on the ceiling of the ROPS/FOPS, an exhaust muffler and the exhaust directed away from the operator. The different sizes of the engines and horsepower ratings of the bulldozers are also a factor, but this comparison can be endorsed as an administrative noise control for selecting the "right-size" machine for the job. Using the largest bulldozer available for common work-tasks can over-expose the operator and the other workers at the construction site to noise, when a small more efficient and most likely quieter bulldozer could do the job.

The road grader had a cab, but no insulation on the walls, floor, or ceiling and the doors were left open during operation decreasing the ability for the cab to provide noise attenuation. In Fig. 5 at low idle, the operator was exposed to an A-weighted sound level (L_A) of 91 dB(A). The highest sustained dose was recorded when the grading was done uphill; the operator was exposed to an A-weighted sound level (L_A) of 104 dB(A). The engine noise appears to be the significant source of the operator's noise exposure, since this operation is done under heavy engine load, and the muffled exhaust is directed away from the cab. For this work-task NIOSH recommends that when a worker's time-weighted noise exposure exceeds 100 dB(A), both earplugs and earmuffs should be worn[3].

The hand saw operator was exposed to noise from the cutting operation, the exhaust noise and the noise of the engine. The highest recorded sound level (L_{eq}) of 114 dB(A) was when the saw first cuts into the concrete at 8:37 (Fig. 6). The operator referred to this task as a "cut-in" and in his opinion this was the loudest part of the job and as the data reflects the operator has accurately recognized this work-task as the loudest part of the job. The road saw operators were not as close to the cutting operation as were the hand saw operators. This takes advantage of the noise control principle of adding distance from the noise source to reduce the sound level reaching the operator. Because the road saws were automated and had good mufflers, the operators were exposed to less noise than the hand saw operators (Fig. 7 and Table 2). But the operator was exposed to a similar cut-in noise as the hand saw operator, a sound level (L_{eq}) of 107 dB(A), because he had to bend over close to the saw blade to insure an accurate start to the cutting. After the cutting cycle was started he could stand and be farther away from the cutting, but still exposed to an A-weighted sound level (L_A) of 104 dB(A). Again, at these high noise level both earplugs and earmuffs should be worn, but NIOSH cautions that even double protection is inadequate when TWA exposures exceed 105 dB(A)[3].

To provide guidance to equipment operators, miners, and equipment manufacturers on technologically and administratively achievable engineering and administrative noise controls the Mine Safety and Health Administration (MSHA) has issued a Program Information Bulletin (PIB) (P04-18)[7]. This PIB, titled: "Technologically Achievable, Administratively Achievable, and Promising Noise Controls," presents technologically or administratively achievable controls or a combination of controls which achieves at least a 3 dB(A) reduction in a miner's noise exposure. This could potentially reduce the REL $Dose_8$ of the most over-exposed worker, the Caterpillar D9G Bulldozer operator by 13,036%. In this PIB MSHA considers the following engineering noise controls, or a combination of these controls, to be technologically achievable in reducing the noise exposure of miners operating surface mobile equipment (e.g., bulldozers, front-end loaders, trucks, graders, scrapers); 1) Environmental cabs (primarily on equipment manufactured since the mid 1970s) that include appropriately selected, correctly installed, and properly maintained acoustical materials, 2) Exhaust mufflers, and 3) Redirection of the exhaust away from the operator. Material and labor cost for the noise control installation will vary from machine to machine, and from region to region. While these costs are not fully calculable for this paper they are according to the PIB economically achievable. For some examples of administrative controls the PIB considers the following to be applicable: 1) Adjust work schedules, 2) Share work tasks and/or rotate workers, 3) Limit duration of work shifts, and 4) Limit the duration of noisy tasks.

3 CONCLUSION

This study documents the extent of noise over-exposure of bulldozer, hand saw, road grader, and road saw operators using both NIOSH REL and OSHA PEL criteria and provides some recommendation to decrease those exposure levels. The data from this study and a series of other studies were used to populate a data base recommended by Suter[4]. The higher operators' noise doses came primarily from the largest bulldozers (Caterpillar D8Hs and D9G built from the late 1960's to early 1970's) which only had ROPS/FOPS and stack exhausts. The newer bulldozers (Caterpillar D8N) having cabs, but no interior sound absorbing material, with ROPS/FOPS protection provided considerably lower operators' noise dose than the older bulldozers (Caterpillar D8Hs and D9G). The newest bulldozer (Caterpillar D6MXL) even without a cab had the lowest recorded operator's dose of all the bulldozers. With proper application of noise controls the bulldozer operators' noise dose could be reduced. Newer equipment with mufflers as opposed to straight-stack exhausts and cabs with interior sound absorbing material have lower in-cab noise levels particularly when doors and windows of the cab are closed.

The road grader had a cab without sound absorbing material. Improvements and modifications such as sound absorbing material to the grader cab would lower the noise levels if the doors and windows were kept closed. The operators of all machines with cabs would be more motivated to keep the windows and doors closed if air conditioning was available and/or working efficiently. Management and site supervisors must be made aware that the noise controls, engineered into the cabs (e.g., door and window seals, barrier and sound absorbing panels) are all compromised by non-working air conditioners. Maintaining the air conditioning is just as important as the barrier and sound absorbing panels for preventing the noise from reaching the operators of heavy equipment.

The hand saw operators where only monitored for 1 to less than 3 hours and still had the third highest noise dose. Monitoring for a full shift of work would likely have resulted in a much higher dose. To reduce noise levels on the gas-powered saws would involve a more comprehensive engineering control effort involving not only the manufacturer of the saws but also the manufacturer of the saw blades, since the noise from cut-in radiated mostly from the blade. Re-engineering of the engine placement, redirection of the exhaust and ergonomic hand controls (placing the hands and head further from the saw), for the hand saws are suggested engineering control considerations. A potential quick fix for the hand saws observed during this study would be a redirected and more efficient exhaust muffler. Hand saw blades have benefited from vibration and sound damping but the same controls have not been fully implemented into large road saw blades. Promotion of these controls can be accomplished through co-operative research programs with major saw blade manufactures.

This paper has discussed four methods of reducing noise over-exposure of construction workers based on the principals of noise control[8]. Figure 8 shows those principles of noise control, and the dependence on compliance with maintenance and behavioral factors. When a machine has a designed noise control in place, such as a cab, the operator must be encouraged to keep the doors and windows shut to have the control work. A well operating air conditioner, available on most machines today, not only encourages the operator to maintain the noise control integrity of the fully enclosed cab, but promotes operator comfort and therefore higher job proficiency[4]. Maintenance must also be

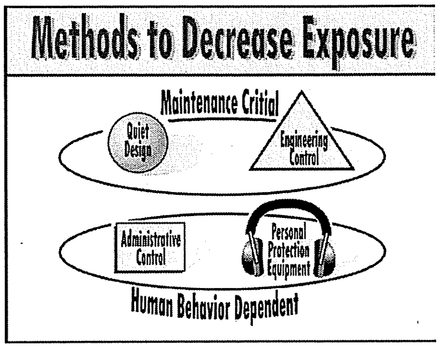

Fig. 8—Methods to decrease worker noise exposure.

scheduled on the air conditioning and door and window seals and latches of the cab, to ensure the effectiveness of this sound absorber/barrier. To retrofit an engineering noise control can involve expense, time and commitment from the safety engineer and/or construction site manager, and could involve increased maintenance on the machine. Management and workers must be supportive of administrative controls since compliance is dependent on human behavior. When personal protection equipment is needed, appropriate training and monitoring can increase the fit and proper use of the hearing protection[3,9]. A variety of HPDs with appropriate attenuation and comfort should be available. An effective Hearing Loss Prevention Program, especially with the daily doses shown in this study, must be established at construction sites with noise problems and include most if not all of these methods to be effective.

Another consideration for management, safety engineers and construction site managers is that a worker overexposed to noise is often more prone to fatigue and is less job proficient[4]. Studies of noisy companies that have implemented hearing loss prevention programs show reductions in accident rates, illnesses, and lost time[10].

While all the construction sites studied provided their workers with earplugs, none checked on the workers use, or made hearing protection mandatory. At the start of the day most equipment operators were observed wearing earplugs, but as the day wore on less operators were seen with hearing protection and by the end of the day very few had earplugs still inserted. Workers and management must recognize the crucial importance of wearing hearing protectors correctly. Intermittent wear will dramatically reduce their effective protection[10]. For example, a hearing protector that could optimally provide 30 dB of attenuation for an 8-hr exposure would effectively provide only 15 dB if the worker removed the device for a cumulative 30-minutes during an 8-hour day. Although those who select hearing protectors should consider the noise in which they will be worn, they must also consider the workers who will be wearing them, the need for compatibility with other safety equipment, and workplace conditions such as temperature, humidity, and atmospheric pressure[9]. In addition, a variety of styles should be provided so that workers may select a hearing protector on the basis of comfort, ease of use and handling, and impact on communication. Additional details on how to select appropriate hearing protection can be found in the NIOSH criteria document—*The best hearing protector is the one that the worker will wear*[3].

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